SinkrOn
JURNAL & PENELITIAN TEKNIK INFORMATIKA
Sinkron : Jurnal dan Penelitian Teknik Informatika
Volume 8, Number 3, July 2024
DOI : https://doi.org/10.33395/sinkron.v8i3.13690
e-ISSN : 2541-2019
p-ISSN : 2541-044X

A Modification Depth First Search (DFS) Algorithm for Troubleshoot Rotating Equipment Diagnosis

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Submitted : May 17, 2024 | **Accepted** : Jun 5, 2024 | **Published** : Jul 1, 2024

Abstract: Rotating Equipment has a role in the industrial production process. There are times when the equipment that is being operated has trouble. Operators have difficulty dealing with problems of rotating equipment due to limited knowledge. To solve this problem we must have an expert with knowledge and experience. Based on this, the problem is building an expert system application to diagnose troubleshoot on rotating equipment which aims to transfer the knowledge that an expert has into the computer so that operator can find out what problems occur. This paper use Depht First Search (DFS) method, namely inward tracing techniques and Forward Chaining, namely the inference method that uses reasoning where to test a hypothesis starts from a fact. This system is equipped with an expert menu for knowledge management, so that experts can add, edit, and delete knowledge. The results showed that DFS and Forward Chaining are very suitable for diagnosing troubleshooting on Rotating Equipment. Based on the reasoning of the experts in their field and adjusted to the symptoms experienced by equipment so that the type of damage is found. It can also assist operators in diagnosing troubleshoot on Rotating Equipment so that operators can take preventive action to prevent further damage to the equipment.

Keywords: DFS, Rotating Equipment, Diagnosis, Expert System, Forward Chaining

INTRODUCTION

Protating equipment functions as moving and shipping equipment as well as energy conversion equipment. These equipment generally have a continuous working frequency for 24 hours per day. Sometimes the equipment will experience trouble. It is important to perform troubleshoot diagnostics on rotating equipment before more serious damage occurs. However, not all operators in the field are aware of the problems that occur in rotating equipment and choose to hand them over to mechanics or engineers. Previous research used the DFS method to find recirculation in mine ventilation systems. The solution procedure for the DFS algorithm is introduced briefly and simply. Furthermore, the DFS algorithm is modified to solve the airflow recirculation case. It can be concluded that in a complex mine ventilation system the DFS algorithm is able to find recirculation. Much work is still being done to simplify the application of using the DFS algorithm in complex copper mine recirculation cases(An et al., 2017). Subsequent research applies the DFS method to find solutions from the Babylon Tower game,

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the results of this study state that the DFS algorithm is able to find steps in the game to reach a solution in the game(Rahmat et al., 2017).

Further research on the main factors of signal usability and reliability in railway control systems. Based on the DFS Algorithm, an automated test approach was developed that took full path coverage and full node coverage as criteria used for rail control systems. The results show that using the DFS algorithmic approach improves the accuracy of test case creation through verification, and handles complex endless loops and state explosion problems (Ménard et al., 2023). The DFS algorithm provides new ideas and new solutions for model based testing in the railway domain(Cheng et al., 2019).

Furthermore, research on applications that are able to diagnose covid 19 using the Forward Chaining algorithm. Where the results of the study stated that the use of the forward chaining algorithm was able to produce applications for diagnosing insider monitoring patients, patients under surveillance, and Covid-19 positive patients. This application is also stated to be able to provide healing solutions from patients (Chaining, 2020). Decision support system is part of a computer based information system that is used to support short and precise decision making. While the forward chaining algorithm is a type of strategy used in the inference mechanism as a test guide(Series, 2021). The database guidelines as a sequence of rules constitute a collection. If each rule is tested, the expert set will evaluate the correctness of the situation. The type of truth condition used is either true or false. If the condition is true, the next rule will be saved and then tested. Otherwise, if the condition is false, the rule is not saved. The rules will be tested under various conditions to produce a conclusion and this process will occur repeatedly. The new data obtained can be stored in the database and the inference rules can be changed as needed, this is one of the advantages of the Forward Chaining method (Aminanto & Ban, 2020).

The method proposed in this paper is a modified Depth First Search (DFS) algorithm to produce results according to case testing. This research proves that the modified DFS algorithm is applied to be able to provide accurate results. Therefore, modifications are needed to obtain optimal test case results.

LITERATURE REVIEW

The Depth-First Search (DFS) algorithm is one of the most fundamental and widely used graph algorithms in computer science. This algorithm is used to search or search in graph or tree data structures in depth (Dimitrov et al., 2024). If at the deepest level a solution has not been found, then the search continues at the node on the right. The left node can be deleted from memory. If at the deepest level a solution has not been found, then the search continues to the previous level. And so on until a solution is found. If a solution is found, then there is no need for a back track process (Arumi & Sukmasetya, 2020). The following is an explanation of how the DFS algorithm works in detail (Aryasena et al., 2023):

Initialization

Starting from the initial node (source node), Use a stack data structure or recursion to track which node to visit next, Then Keep a list of visited nodes to avoid repeat searches.

Search Steps

Using Recursion

Starting from the starting node, mark the node as visited. For each neighbor of the node being visited, If the neighbor has not been visited, perform DFS recursively on the neighbor

Using Stacks

Push the starting node onto the stack. While the stack is not empty , Grab (pop) the node from the top of the stack. If the node has not been visited, mark it as visited. Push all unvisited neighbors of that node onto the stack.

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The advantages of the DFS algorithm are that the memory required is generally less than BFS (Breadth-First Search), especially for large graphs and is easy to implement both recursively and iteratively (Jürß et al., 2023). Meanwhile, the disadvantages are that it doesn't always find the shortest path and can fall into a loop if the graph contains cycles and the vertices are not marked as visited (Joshi et al., 2023).

Forward Chaining is an inference technique in expert systems and artificial intelligence (AI) that is used to draw conclusions from a set of existing facts or data. This technique is a form of data-driven reasoning, where inference starts with known facts and uses logical rules to reach new conclusions. Forward chaining is often used in systems that require decision making based on rules, such as medical diagnosis, control systems, etc (Akil, 2020). The way the forward chaining algorithm works starts from initialization, namely starting with a set of known facts or initial conditions (Aminanto et al., 2020). Then Rule Evaluation is Each rule in the knowledge base is evaluated to see whether the premise (IF condition) of the rule is satisfied by the existing facts (Series, 2021). Next is Rule Application where if the premise of a rule is fulfilled, then the action (THEN condition) of the rule is executed, which usually produces new facts. Final Iteration, This process is repeated with new facts added to the existing set of facts, until no more rules can be applied or a certain goal is achieved (Henderi et al., 2020). There are several advantages of Forward Chaining, namely Simple and Intuitive, Data-Driven, and Reactive. Meanwhile, the disadvantage is that it can be inefficient if there are too many rules because each rule must be evaluated every time a new fact is added and is not focused (Hays et al., 2020). Forward Chaining is a powerful method of rule-based reasoning and has been widely used in various artificial intelligence applications to solve problems that require logical inference from available data (Ogheneovo & Nlerum, 2020). Forward chaining applications such as expert systems, control systems and recommendation systems (Hays et al., 2020). Expert systems are useful for diagnosis, troubleshooting and decision making (Dwi Putra, 2018).

An expert system is a system whose performance adopts the expertise of an expert in a particular field into a system or computer program that is presented with a display that can be used by users who are not experts so that with this system the user can make decisions or determine policies like an expert (Ogheneovo & Nlerum, 2020).

METHOD

An expert system is a system whose performance adopts the expertise of an expert in a particular field. Furthermore, that knowledge is entered into a computer system or program that is presented with a display that can be used by non-expert users so that with this system users can make decisions or determine policies like an expert (Dwi Putra, 2018). An Expert systems are a branch of science from artificial intelligence. An expert system is a system that seeks to translate human understanding so that it can be entered into a computer to be able to solve problems like an expert (Gao et al., 2017). In android-based applications, this expert system can also be applied. In general, the structure of an expert system consists of four components (Joshi et al., 2023). These components are Knowledge Base, Database, Inference Engine and User Interface (Ghotbi-Maleki et al., 2020).

Depth First Search (DFS) is a vertex search algorithm in a graph that runs inward. In searching with the DFS algorithm, the search starts from the very first level (level 0 or left level). If at the first level the solution has not been found, then the search is continued on the right hand graph and then continued to the leftmost child at the next level (level 1) and so on until there are no more children or a deeper level(Champagne Gareau et al., 2023). If the search has reached the innermost node or child, backtracking will be carried out to search for the next child node. In the DFS algorithm, memory usage is not much because only nodes on the active path are stored (Yang et al., 2024). In addition, if the solution you are looking for is at the deepest and leftmost levels, then DFS will find it quickly (Champagne Gareau et al., 2023). Flow of DFS Algorithm on Figure 1.

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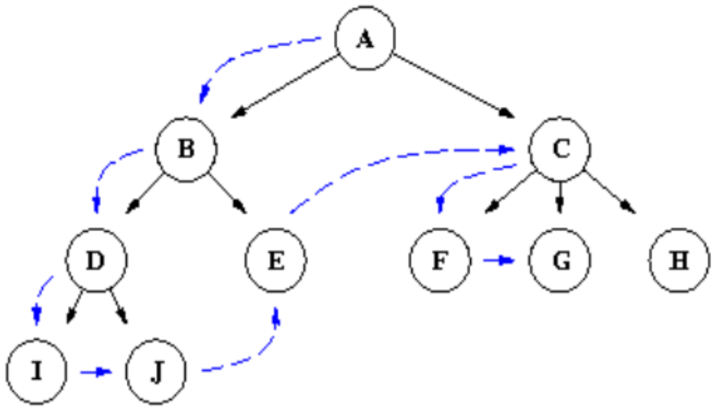

Fig 1. Flow of DFS Algorithm

In the case of figure 1, the path taken to find the destination point 'G' is A-B-D-I-J-E-C-F-G. In the DFS algorithm, each symptom will be executed according to the rules that are executed. A new conclusion is obtained based on the final node, when the rule has been executed. Next, to get to the final node D we need a connecting node ABC = D. In this condition the symptoms A, B, C are true. One of the advantages of this DFS algorithm is that the amount of memory used is only for calculating the nodes used, so it does not use a lot of memory (Jain, 2023).

The Forward Chaining system model consists of 4 main components, namely the user, working memory, inference engine, and rule base. Forward Chaining algorithm is a conclusion drawing strategy that starts from a number of known facts to get a new fact by using rules that have premises that match the facts and continue until they get the goal or until there are no rules that have a suitable premise or until you get the facts (Sastrawan et al., 2021). The Forward Chaining method is a search method that starts evaluating with known records, then matches the information with the IF part of the IF-THEN rule (Janson, 2023). The rule will be executed if there is a fact that matches the IF part. Furthermore, if the rule is executed, the new truth obtained will be entered in the database. To reach a conclusion, appropriate symptoms are needed. The pseudocode of the Forward Chaining algorithm can be seen in Figure 2 below.

```
Repeat
for each symptom do
    if indication = rule symptoms then
        next rule symptoms
    else
        next symptoms
    end if
end for
until diagnosis found
```

Fig 2. Pseudocode Forward Chaining Algorithm

In this study, the author uses the System Development Life Cycle (SDLC) method. A brief illustration of the SDLC method which consists of several stages is provided in Figure 3.

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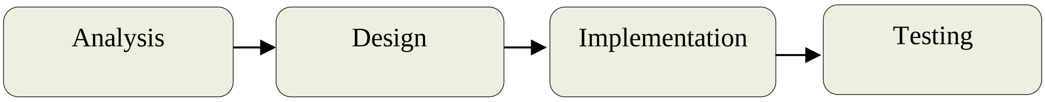

Fig 3. System Development Life Cycle

The study stages used in this study are:

Analysis
At the analysis stage, data is needed as an initial design before making a design or application. The data collection technique at this analysis stage is using interview techniques where several questions are asked to experts or here are Plant Support Maintenance Engineers (MPS) who have understood the condition of the equipment.
Design
At the Design stage, the software program includes data structures, software architecture, interface representations, and software procedures from the analysis stage to the design representation so that they can be implemented into the program at a later stage.
Implementation
At this stage, the implementation of the system uses a particular programming language that is tailored to the needs of the system to be used.
Testing
At this testing stage, first ensure that the software has been functionally tested for suitability and minimized various errors.

RESULT

At this stage, data was collected from interviews with the Plant Support Maintenance Engineer (MPS) and several references related to research. The data obtained are in the form of damage data, symptoms and solutions as shown in the table below:

Table 1. Table of Damage

Code	Damage Type
P001	Faulty pump bearing
P002	Protecting tube middle broken
P003	Poor lubrication
P004	Looseness bearing with misalignment
P005	Looseness bearing
P006	Bearing defect
P007	Lifetime rubber has been reached
P008	Diaphragm membrane is damaged
P009	Corrosion and lifetime
P010	Overclearance between power and idler rotor
P011	Wear between stationary and rotary
P012	No disease
P013	No disease
P014	No disease

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Table 2. Table of Symptoms

Code	Symtoms Name
G001	There is noise/abnormal a sound during operation
G002	High vibration
G003	Pump experiencing low pressure and cavitation
G004	Mechanical seal and pump casing leaking with a change in the oval shape of the coupling hole
G005	High Vibration exceeds the danger limit
G006	High vibration with cavitation of pump
G007	The pump coupling is damaged and the coupling hole is deformed
G008	No pressure and flow meter reading
G009	Damage to the tum block and road end bearing
G010	Mechanical seal is leaking
G011	The pump has low performance accompanied by over clearance in the pump bearing
G012	OB side deflector broken

From the results of the knowledge base described in the table above, a decision tree is then formed to make it easier to implement the DFS algorithm into the system.

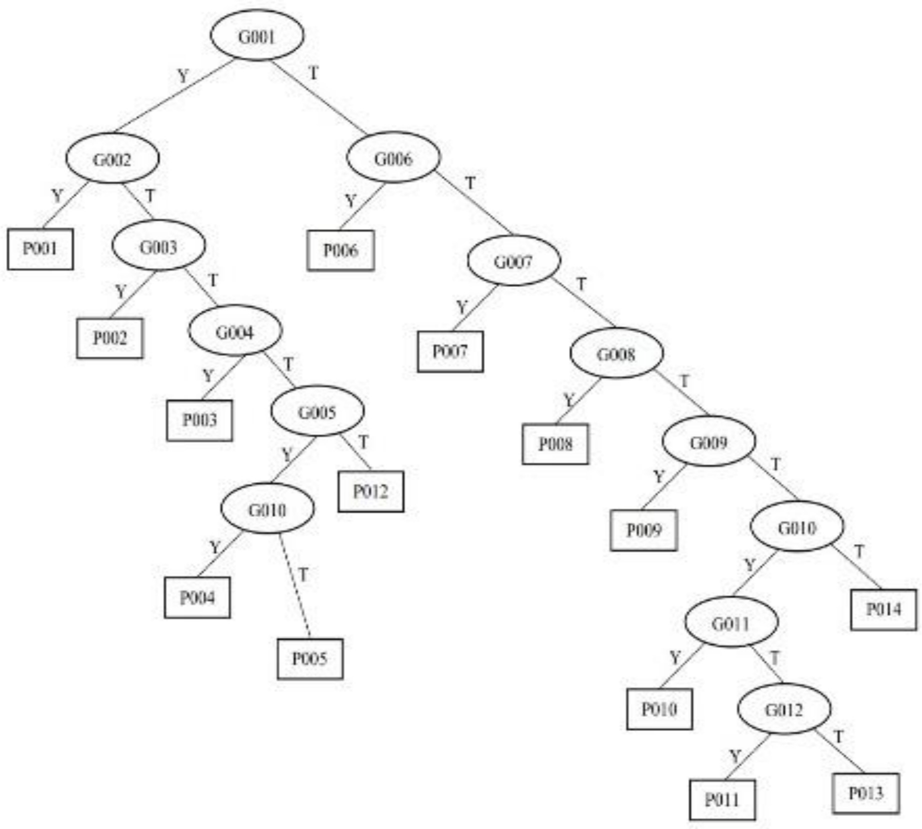

Fig 4. DFS Decision Tree

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Based on the decision tree picture above, then the rules are formed using the Forward Chaining algorithm. The rule table can be seen in table 3.

Table 3. Table of Rule

No	Rules
1.	IF abnormal noise is heard during operation (B001), AND high vibration (G002), THEN pump bearing damage (P001)
2.	IF there is noise/abnormal noise during operation (G001), AND the pump is subjected to low pressure and cavitation (G003), THEN protecting middle tube is damaged (P002)
3	IF abnormal noise is heard during operation (G001), AND The mechanical seal and pump casing are leaking accompanied by a change in the oval shape of the coupling hole (G004), THEN is poor lubrication (P003)
4	IF abnormal noise is heard during operation (G001), AND High vibration exceeds the hazard limit (G005), AND the mechanical seal is leaking (G010), THEN is bearing looseness with misalignment (P004)
5	IF abnormal noise is heard during operation (G001), AND High vibration exceeds the danger limit (G005), THEN bearing is loose (P005)
6	IF High vibration is accompanied by cavitation in pump (G006), THEN bearing damage (P006)
7	IF The clutch pump is damaged and deformed in the clutch hole (G007), THEN the age of the rubber has been reached (P007)
8	IF No pressure and flow meter reading (G008), THEN diaphragm membrane is damaged (P008)
9	IF Damage to tum block and end bearing (G009), THEN corrosion and service life (P009)
10	IF the mechanical seal is leaking (G010), AND the Pump has low performance accompanied by excess clearance in the pump bearings (G011), THEN the oven clearance between power and idler rotor (P010)
11	IF mechanical seal leaked (G010), AND side deflector OB broke (G012), THEN wear between stationary and rotary (P011)

System design means describing the appearance and workings of the system globally, including the design of Use case diagrams, scenarios from Use cases, Activity diagrams, Sequence Diagrams, and Class Diagrams as well as the program menu structure of the system to be created and implemented.

Use Case Diagram is a model for the behavior (behavior) of the information system to be made. The use case diagram for Troubleshoot Diagnosis on Rotating Equipment uses the DFS algorithm and Forward Chaining.

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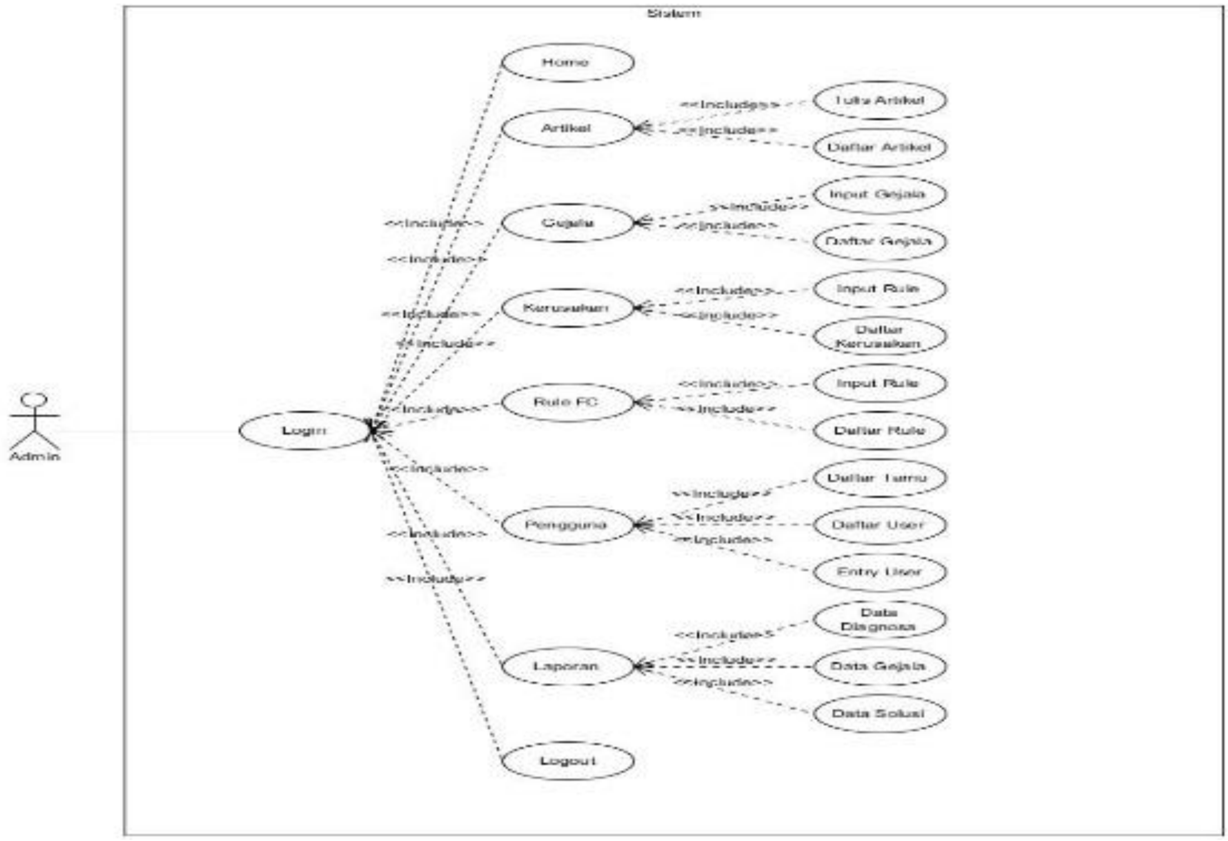

Fig 5. Admin/Expert Login Diagram Usecase

The system design can be described using the Activity Diagram as follows:

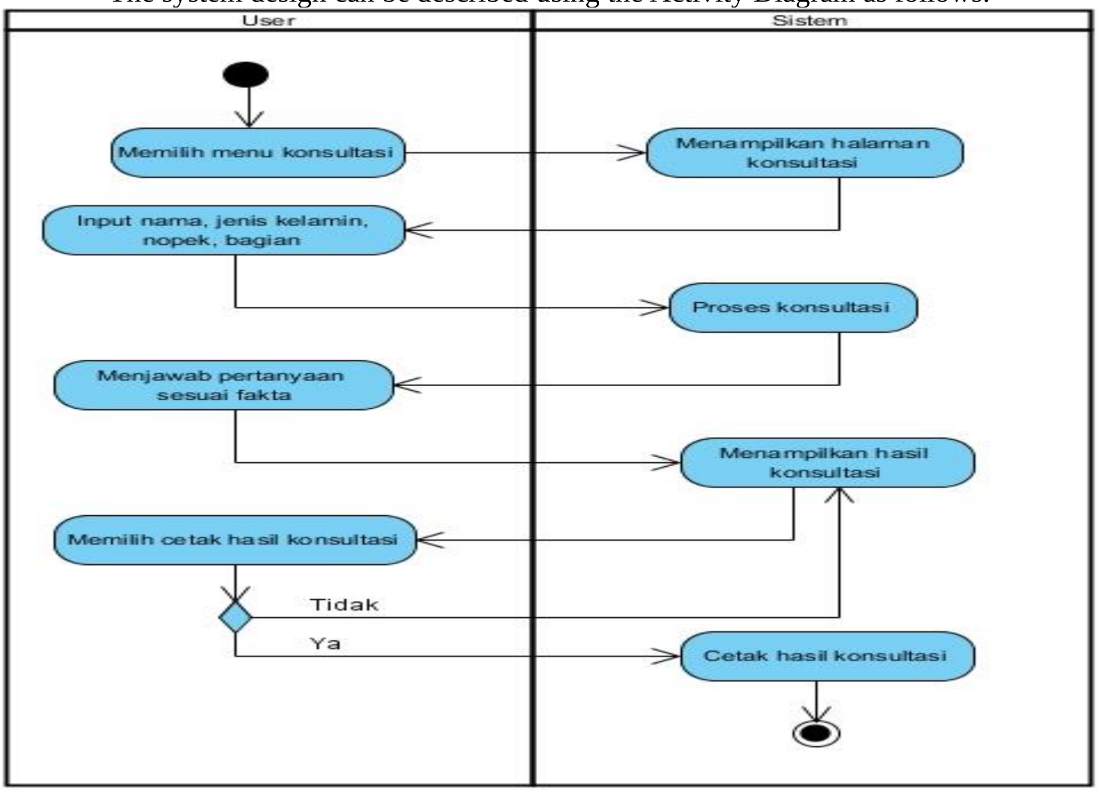

Fig 6. Consulting Activity Diagram

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e-ISSN : 2541-2019
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Sequence Diagrams are used to describe a scenario or a series of steps taken as a response to an event to produce a certain output. Class Diagram is a specification that when instantiated will produce an object and is the core of object-oriented development and design. A class diagram is used to show the existence of classes and their relationships in the logical view of a system. Figure 7 and Figure 8 below show sequence diagrams and class diagrams.

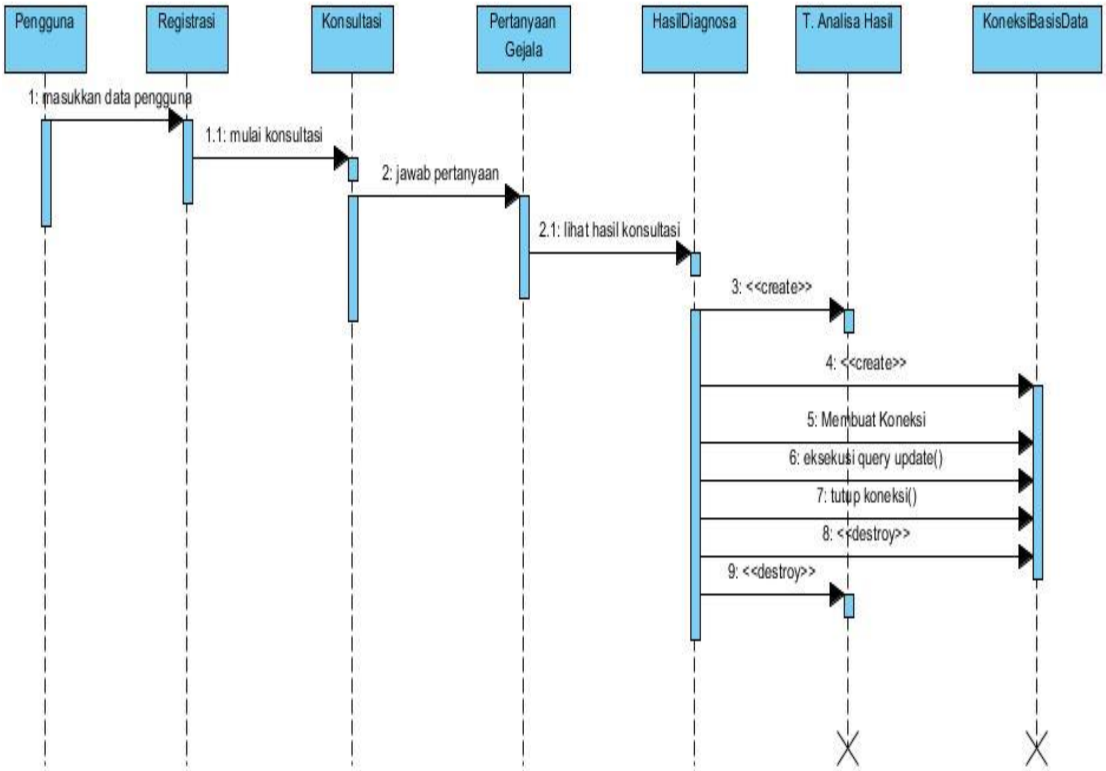

Fig 7. Sequence Diagrams

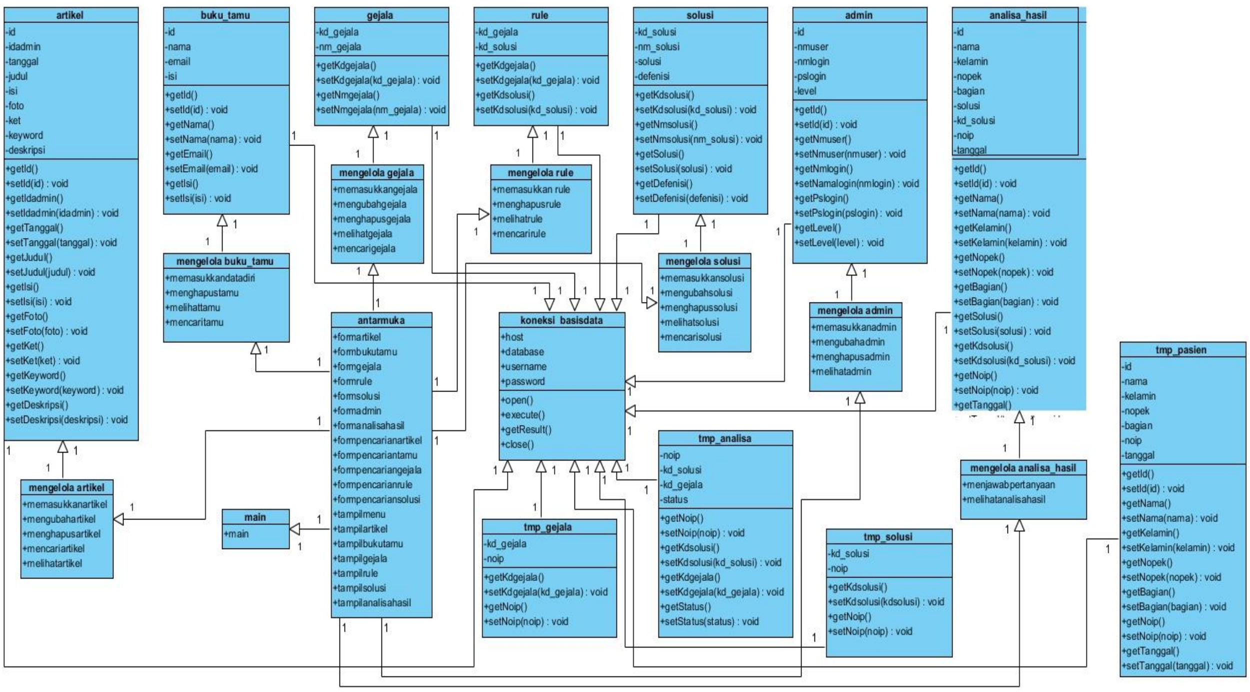

Fig 8. Class Diagrams

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The main page of the user or the user is as follows .

Fig 9. The main page of the user

Consultation Registration page to register before the user performs a consultation with the following display.

Fig 10. Consultation Registration Page

DISCUSSIONS

In the context of troubleshoot diagnosis on rotating equipment, we can combine the Forward Chaining method in the DFS Algorithm to get the benefits of both. Modification of the DFS algorithm by combining the Forward Chaining method is applied in several cases, such as:

Rule Graph Model

Represent a diagnosis system as a graph, where nodes are conditions or symptoms and rules are edges connecting the nodes.

DFS for Search

Use DFS to explore rule graphs in depth, looking for paths from initial symptoms to final diagnosis.

Forward Chaining for Inference

Apply forward chaining along the paths discovered by DFS to infer new facts and reach a diagnosis.

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Forward chaining utilizes diagnostic rules to infer new facts from already known facts. Through iterative application of these rules, the system can enrich the fact set and achieve a more accurate diagnosis. A systematic inference process ensures that all relevant facts are considered, reducing the possibility of misdiagnosis.

Modifying the DFS algorithm for the Troubleshoot Rotating Equipment Diagnosis case can improve the performance of the DFS Algorithm itself. Improving the performance of the DFS algorithm using the forward chaining method can be explained in three ways, namely:

Efficiency

The DFS algorithm can be more efficient in finding solutions in graphs with large depth. The rule graph representation allows flexibility in defining various conditions, symptoms, and diagnostic rules. This makes it easy to add or change rules without disrupting the overall structure of the system. A clear graph structure makes it easier to visualize diagnostic pathways and helps technicians understand the logic flow used to reach a diagnosis.

Compatibility

Rule-based systems can be directly integrated with DFS algorithms for deeper and more structured searches.

Scalability

Allows adding new rules and new nodes in the graph without changing the overall structure of the algorithm.

Thus, modified forward chaining using the DFS algorithm offers a more efficient and structured approach to rotating equipment diagnostics, especially in complex systems with many rules and possible diagnostic paths. This modification of the DFS algorithm is scalable to be applied to complex diagnostic systems with many rules and symptoms. The DFS algorithm is capable of handling graphs with a large number of vertices and edges, while forward chaining ensures inference remains efficient. The system can be expanded by adding more rules and conditions without the need to make major changes to the core algorithm.

CONCLUSION

The conclusion of this research is the Depth First Search (DFS) Algorithm and the Forward Chaining method to diagnose Troubleshoot Rotating Equipment on this system assist in transferring expert knowledge into the computer by entering a knowledge base in the form of 12 symptoms and diseases or damage totaling 11 diseases on the equipment, so that users have no trouble getting equipment malfunction information.. This expert system application assists the user in dealing with Troubleshoot when problems occur with Rotating Equipment so that the user can take preventive actions first to prevent more severe damage. Through modification of the DFS algorithm and forward chaining, we can carry out troubleshoot diagnosis on rotating equipment more effectively. The DFS algorithm allows a deep and structured search of the rule graph, while the forward chaining method allows systematic inference from known facts towards a final diagnosis. This approach can increase efficiency and accuracy in detecting and diagnosing problems in rotating equipment. With a more efficient and accurate diagnostic system, companies can reduce downtime, increase operational efficiency, and prevent further damage to equipment.

Further research can be carried out to combine DFS and forward chaining with other diagnostic techniques such as machine learning or big data analysis to increase the accuracy and speed of diagnosis. The use of techniques such as vibration analysis or thermography can be integrated with these systems to provide reliable input data. richer and more varied. Further implementation and research in this area has great potential to bring significant improvements in operational efficiency and maintenance of industrial equipment

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